Reply to Comment on "Dynamics of Weak First Order Phase Transitions"

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In the preceding Comment [1], Harris and Jungman (HJ) offer interesting criticism to the interpretation I advanced in the Letter titled "Dynamics of weak first order phase transitions" [2]. In order to clarify my position, it is worthwhile spending a few sentences restating both my results and HJ's comments in a language which may bridge most of our differences.

The aim of this work was to study numerically the role thermal fluctuations play in promoting phase mixing in a system described by a Ginzburg-Landau free-energy density with two minima which are degenerate at the critical temperature T_c. Below T_c one minimum has lower free energy and thus becomes thermodynamically preferred. Let's call this free energy the *mean field* free energy. This mean field free energy has an implicit coarse-graining scale, the mean-field correlation length, which is its inverse curvature. In the simulations, the lattice spacing was chosen to be smaller than the correlation length at all temperatures. The idea was to prepare the system initially in the minimum which is metastable below T_c and measure the fraction of the total area (the simulation was done in 2d) which remains in this phase as the system evolves according to a Markovian Langevin equation. The simulations were done at T_c, and the parameter which I chose to vary was the coefficient of the cubic coupling, α, which measures the strength of the *mean field* thermodynamic barrier between the two phases. I found that below a certain value of α, called α_c, the two phases mixed completely, while for $\alpha > \alpha_c$ the system remained well-localized in the initial phase. Thus, even though the *mean field* free-energy density had a barrier separating the two phases for $\alpha < \alpha_c$, the system is better described by a free-energy density with only one minimum, located at the top of the barrier between the two phases. In other words, the thermal fluctuations washed away the first-order phase transition.

At α_c I observed that the system exhibited critical slowing down, as it should in the vicinity of a second order phase transition. What I failed to stress in a clear fashion in my Letter, as pointed out by HJ, is that this symmetry restoration is equivalent to the symmetry restoration of the Ising model due to the breakdown of the *mean field* approximation. This was implicitly assumed at the end, when I used the same notation for the critical exponent (β) controlling the divergence of the order parameter $\Delta F_{\rm eq}$ with α_c as the magnetization M

with T_c in the Ising model. Indeed, in a previous publication [3], I showed that a simple field redefinition brings the system with a cubic term into a Ginzburg-Landau model with a complicated magnetic field which vanishes at T_c. No news here, except for the fact that the quadratic term is written as $-\frac{\alpha^2}{18\lambda}T_c^2\phi^2$. Thus, as α is decreased, so is the magnitude of the quadratic term, leading to an eventual breakdown of the *mean field* approximation for $\alpha < \alpha_c$. As is well-known, the effect of incorporating fluctuations is precisely to decrease the critical temperature from its mean field value [4]. At one-loop, and in a 2d lattice, the term has the log form with a hard momentum cutoff described by HJ. There are also finite terms which complicate the issue somewhat. (See also Ref. [5], where all these terms were computed.) Thus, by incorporating fluctuations, the *effective* coarse-grained potential (called continuum limit by HJ) would differ from its mean field version, in that the barrier would disappear at α_c. (Note also that the value of α_c will depend on the lattice spacing, since the renormalization terms are lattice-space dependent!) This is the conclusion of HJ, with which I of course agree. However, I believe my interpretation still remains valid, as it was based on the *mean field* free energy. This is the quantity which is widely used when describing cosmological phase transitions. In this context, the one-loop corrected effective potential plays the same role as the mean field Ginzburg-Landau free energy, in that (in general) it incorporates the effects from all fields coupled to the scalar field, but *not* from the scalar field itself. Although I focused on a real scalar field, the results are suggestive of the role of fluctuations in destroying the "strong" character of the transition. In fact, for a real scalar order parameter, "weak" first-order transition is a misnomer.

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